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TABLE OF CONTENTS

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RESEARCH ON RADIO FUSE JAMMING TECHNOLOGY

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ABSTRACT: This paper discusses the working mechanism of the Doppler fuse and its antijamming approaches, and proposes a technology and methodology for jamming continuous-wave Doppler fuses. Based on this, the author arrives at a final conclusion that the jamming capability of the interferometer and the interferometer proper are closely associated with the characteristics of fuse as well as tactical conditions.

KEY WORDS: radio fuse, electronic jamming countermeasures, electronic jamming.

0.Introduction

As a significant integral part of electronic countermeasures, radio fuse countermeasures occupy a unique position in the future warfare. A radio fuse has two major features: (1) it can be applied day and night under all kinds of conditions without being affected by weather; and (2) it can be used to deal with any target that reflects radio waves. Thus,

the radio fuse can be used to tackle not only air targets, but ground ones as well.

In fact, since World War II, radio fuses were widely applied and developed, and its reliability has been greatly enhanced. One of the developments is the ring antenna, which has been used for the continuous-wave Doppler fuse in place of the previous missile body antenna. In the early sixties, a missile fuse with a nuclear warhead was developed in the United States. Again, in the late seventies, America developed multipurpose fuses, laser fuses, and delayed power-connection fused which marked a new level in fuse development.

1. Doppler Fuse

The single-channel Doppler fuse developed in the United States has four major models: continuous-wave (CW) fuse, frequency modulation (FM) fuse, pulse Doppler (PD) fuse and noise fuse. Assuming the radiation signal of these fuses is:

$$e_t(t) = A(t) \cos [\omega_0 t + \varphi(t)] \qquad (1)$$

where ω_0 is carrier frequency; for CW fuse, A(t) is a constant, φ(t) is also a constant, while for the FM fuse, A(t) is a constant. If modulated with sine waves, then

$$\varphi(t) = \Delta\omega \sin (\omega_0 t + \varphi_0)$$

For PD fuses, A(t) is a pulse wave; φ(t) is a constant under ideal conditions, and basically is not correlated with the radio frequency phase of continuous pulse; while for the noise fuse, both A(t) and φ(t) are random variables.

The following discussion is focused on the formation of radio frequency-triggered signals.

The return wave of fuse-radiated signal reflected back from a target is:

$$e_r(t) = K_0 e_t(t - \Delta t) = K_0 A(t - \Delta t) \cos [\omega_0 (t - \Delta t) + \varphi(t - \Delta t)] \qquad (2)$$

If the fuse moves relative to a target at an even speed, i.e.,

$$\Delta t = \Delta t_0 - (\omega_d/\omega_0)t$$

Δt_0 is a constant

ω is Doppler frequency

then Eq. (2) becomes:

$$e_r(t) = K_1 A[t(1+\frac{\omega_d}{\omega_0}) - \Delta t_0] \cos \{(\omega_0 + \omega_d)t - \omega_0 \Delta t_0 + \varphi[t(1+\frac{\omega_d}{\omega_0}) - \Delta t_0]\} \quad (3)$$

In Eq. (2), K_0 is incorporated into K_1, in which, K_1 is the multiplier gain. To make the fuse generate an ignition signal during a normal start, the fuse receiving device has to enable $e_r(t)$ and $e_t(t)$ to obtain a new frequency component through the multiplier, i.e., by multiplying Eq. (1) by (2),

$$\begin{aligned} e_t(t) \cdot e_r(t) &= \frac{1}{2}K \cdot A(t) \cdot A[t(1+\frac{\omega_d}{\omega_0}) - \Delta t_0] \cdot \cos\{2\omega_0 t \\ &+ \omega_d t - \omega_0 \Delta t_0 + \varphi(t) + \varphi[t(1+\frac{\omega_d}{\omega_0}) - \Delta t_0]\} \\ &+ \frac{1}{2}KA(t)A[t(1+\frac{\omega_d}{\omega_0}) - \Delta t_0] \cdot \cos\{\omega_d t - \omega_0 \Delta t_0 \\ &+ \varphi[t(1+\frac{\omega_d}{\omega_0}) - \Delta t_0] - \varphi(t)\} \end{aligned} \quad (4)$$

where K is a coefficient factor for the insertion loss of K_1 and filter. When the condition $\omega_d \ll \omega_0$ is satisfied, then we have

$$e_t(t) \cdot e_r(t) = \frac{1}{2}KA(t)A[t(1+\frac{\omega_d}{\omega_0}) - \Delta t_0] \cdot \cos\{\omega_d t - \omega_0 \Delta t_0 + \varphi[t(1+\frac{\omega_d}{\omega_0}) - \Delta t_0] - \varphi(t)\} \quad (5)$$

the term $\varphi[t(1+\frac{\omega_d}{\omega_0}) - \Delta t_0] - \varphi(t)$ in the equation varies slowly with time, and it can be considered as an invariable within several periods of radio frequency ω_0. To ensure normal start and ignition, a passband filter with Doppler frequency ω_d is applied in the low-frequency segment of the receiving device in the CW fuse, the PD fuse, and the noise fuse. In these fuses, only the spectrum component close to ω_d from the $e_t(t) \cdot e_r(t)$ frequency spectrum can pass since it possesses the highest energy. Whereas for the FM fuse, there are a number of peak values in $e_t(t) \cdot e_r(t)$ spectrum; this broad spectrum contains $\omega_d \pm n\omega_m$ components (m=0,1,2,3....).

The variation of the amplitude of the idealized Doppler signal in the foregoing fuse $A_d(\Delta t)$ with time is shown in Fig. 1[1], while the amplitude of its Doppler component is listed in Table 1[1]. Based on the respective features of the amplitude $A_d(\Delta t)$ in these fuses, the frequency response curves of the low-frequency amplifier and Doppler passband filter can be designed.

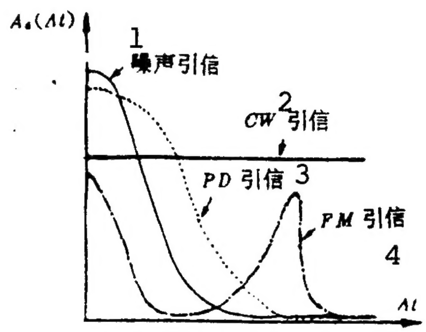

Fig. 1. Relation curves of $A_d(\Delta t)$ and Δt [1]
KEY: 1 - noise fuse 2 - CW fuse 3 - PD fuse
4 - FM fuse

TABLE 1. Amplitude of Doppler Frequency Component

1 引信类型	多普勒分量 $A_d(\Delta t)$的数值 2	3 特殊的假设
CW	K	
J_0—FM	$\frac{1}{2}Kc^2J_0\left(\frac{2\Delta\omega}{\omega_m}\sin\frac{\omega_m\Delta t}{2}\right)$	4 $A(t)$为常数 c
PD	$\frac{K}{T}e^{-a\Delta t^2}\int_c^{\Delta-\Delta t} e^{2ax^2}dx$	5 对 $mT<t<mT+\Delta$ 脉冲包络，$A(t)=Ae^{at^2}$；m 为整数，T 为间歇时间
噪声 6	$\frac{K\sin(\pi\Delta\omega\Delta t)}{(\pi\cdot\Delta\omega\cdot\Delta t)}$的包络 7	具有带宽为 $\Delta\omega$ 的矩形噪声频谱 8

KEY: 1 - type of fuse 2 - numerical value of Doppler component 3 - special assumption
4 - A(t) is a constant 5 - For pulse envelope ...., $A(t)=Ae^{u,2}$; m is an integer, ... while T is interval time
6 - noise 7 - the envelope of
8 - rectangular noise spectrum with a bandwidth

2. Discussion of Radio Fuse Jamming Countermeasures

To jam a radio fuse, the ideal approach is to make the fuse explode early or make it blocked beyond its normal operating range (or beyond the effective kill range of missile), namely, to make the normal operation probability of fuse equal to zero. The fuse jamming equation is as follows:

$$P_j = \frac{K_F P_s D_s A_0 R_j^2}{D_j 4\pi H^4 F^2(\theta_s) F^2(\theta_j) \gamma_j} \frac{\Delta F_j}{\Delta f_s} \tag{6}$$

where

P_j is the power of the interferometer;

K_F is the jamming coefficient, which is equivalent to the minimum ratio between the jamming power (the power that initiates the fuse) received by fuse within the passband range P_j and the echo wave power of the target (within the operating range of the fuse) P_s:

$$K_F = \left(\frac{P_j}{P_s}\right)_{min}$$

P_s is the radiation power of the fuse

D_s is the directional coefficient of the fuse's receiving antenna

A_0 is the effective reflection area of the target

R_j is the distance between the fuse and the interferometer

D_j is the directional coefficient of the interferometer's transmission antenna

$F(\Theta_s)$ is the directional function of the fuse's receiving antenna

$F(\Theta_j)$ is the directional function of the interferometer's transmission antenna

H is the normal operational height of the fuse

γ is the polarization coefficient of antenna (the possible inconsistent polarization of fuse signal and jamming signal is not taken into account

ΔF_j is the jamming signal spectrum

Δf_s is the fuse passband.

It can be seen from Eq. (6) that the following relations exist between the characteristics of fuse and its anti-jamming capability:

The jamming power P_j is in direct proportion to the fuse transmission power P_s, i.e., it takes a high jamming power to jam a high-power fuse. Thus, by increasing P_s, the anti-jamming capability of fuse can be enhanced.

The better the directivity of antenna, the higher the anti-jamming capability that the fuse can have, and the harder it is to jam the fuse, i.e., the higher jamming power needed for interfering the fuse. In side lobe jamming, since the directional function $F(\Theta_s)$ is a few orders of magnitude lower than that during the major lobe jamming, the jamming power should be correspondingly increased by a few orders of magnitude so as to achieve efficient jamming. Therefore, the major lobe should be aligned as much as possible during the jamming.

P_j is in direct proportion to the reflection area of the target A_0, i.e., the larger the effective reflection area of the target, the higher the jamming power that is required.

P_j is in direct proportion to the passband of the fuse's receiver. Thus, by compressing the passband, the anti-jamming capability of fuse can also be improved. For better jamming effect, the spectrum of jamming signal is required to be as broad as possible, and the frequency is required to be aligned.

To reach similar jamming effect, different K_F are required for different radio fuse systems. Therefore, the value of K_F reflects the anti-jamming capability of an electrical circuit.

By lowering the sensitivity of the fuse's receiver to make the fuse's normal operating distance shorter, the anti-jamming

capability can also be upgraded.

In addition, the application of anti-jamming safety devices is also an available approach. Here, at a short distance from a target missile, by giving a long-range start instruction to plug in the fuse's power source, the time for the electromagnetic radiation of fuse can be greatly reduced, and it would be more difficult for the opponent to detect and jam the fuse.

The foregoing discussion covered several technical approaches related to fuse jamming. However, it would be equally hard to take multiple anti-jamming measures for one kind of fuse systems. Yet tactically speaking, fuse operation can indeed create a complex electromagnetism environment to protect itself from being detected and interfered. The normal conditions are as follows:

The frequency range of the fuse radiated signals is extremely wide. For instance, it allows one launcher to fire fuses of the same category but with different carrier frequency (the scattering difference of carrier frequency is intentionally enlarged during fuse design and manufacturing), or different launchers to fire fuses of different categories and with different carrier frequency.

The quantity of fuse signals varies considerably, including single firing, multiple and continuous firing, and simultaneous firing. The number of fuse signals is large, and they are distributed within a very wide frequency range.

The flight trajectory of missiles is changing. The alteration of firing patterns, such as the change of firing elevation angle, can cause a major difference in the flight trajectories of missiles. Hence, an extension of air domain is required for efficient detection and jamming.

The time spent by a fuse in the air is short. For the general far-dissociation and near-explosion fuse (NVT), after a missile is launched to a safe distance, the battery inside the fuse device is activated and powered. The time from radiation of electromagnetic waves to normal explosion of the fuse is approximately 10-30s (depending on the missile range).

While the controllable far-dissociation and near-explosion fuse (CVT) adopts an anti-jamming safety device, namely, the fuse power source is plugged in when the missile is relatively close to the target. The time of radiated signals from a fuse in the air is short, normally 2-3s. Technically, it is quite difficult to realize effective fuse detection and jamming when there are multiple signals, and a single signal stays in the air for such a short time.

3. Analysis of Radio Fuse Jamming Technology

From fuse jamming equation (6), the jamming range is related to the performance of the fuse and the interferometer. To increase the jamming range without increasing the interferometer power, a directional antenna can be applied in the jamming transmitter to cause the jamming spectrum and signal spectrum to overlap as much as possible. When the directional antenna is applied, the effective jamming sector is decreased, which can lead to an immense decrease of tactical performance of the interferometer.

Thus, when an interferometer is used to protect ground targets, the space taken by possible trajectories of each artillery shell, as well as the effective space formed due to the directivity of the interferometer antenna and the fuse antenna should be taken into account. While in tactical applications, it is extremely difficult to determine the location of the interferometer protection area because of the effect of tactical

factors.

At present, two kinds of jamming systems, i.e., sweep frequency jamming and retransmission jamming have been designed for radio near-explosion fuse jamming at home and abroad. In these two interferometers, the detection and reception guidance is based on a search type super-heterodyne receiving system. This system can adapt to the meter and decimeter waveband electromagnetic signal environments for its detecting and receiving sensibility, dynamic range, and signal processing capabilities. To increase the effective radiation power of the two systems, the transmission system normally adopts space power synthesis and can perform directional transmission with a two-antenna array. In applying sweep frequency jamming to the continuous-wave Doppler radio near-explosion fuse, the sweep frequency velocity and modulating signal waveform should be correctly designed.

Fig. 2 is a simplified block diagram showing the generation of sweep frequency jamming waveforms. Normally, the radio frequency receiving bandwidth in the meter waveband fuse receiving device is designed as approximately 200kHz, while the accumulative time of jamming signal voltage in the fuse receiving device is approximately 40ms. If a square wave modulating signal with a duty ratio 1:1 is used to generate double waveband jamming, the number of targets that can be efficiently interfered per second would be:

$$N=\frac{100\text{ms}}{40\text{ms}}\times 2=50(\text{个})$$

The sweep frequency velocity should be correctly designed so as to ensure that the jamming signal voltage has an adequate accumulation time in the fuse receiving circuit. The frequency of modulating signal should imitate the Doppler frequency of the continuous-wave Doppler fuse.

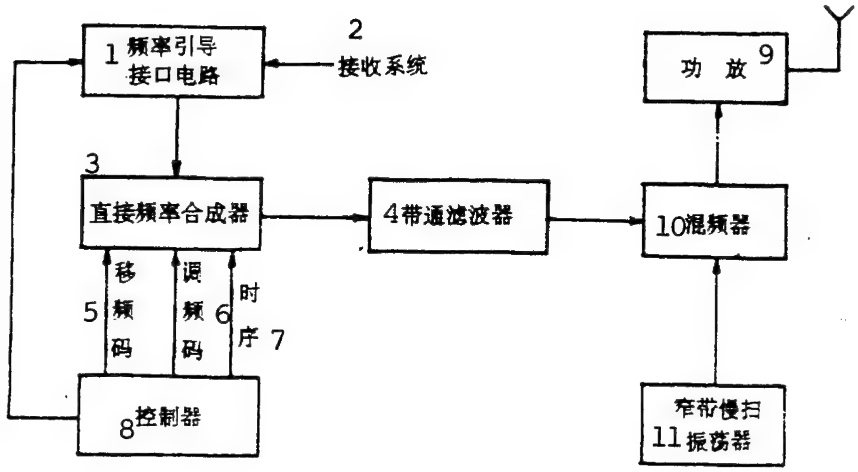

Fig. 2. Block diagram showing generation of sweep frequency jamming waveforms
KEY: 1 - frequency guided interface circuit
2 - receiving system 3 - direct frequency synthesizer 4 - passband filter
5 - frequency shift code 6 - frequency modulation code 7 - time sequence
8 - controller 9 - power amplification
10 - frequency mixer 11 - narrow-band slow sweep oscillator

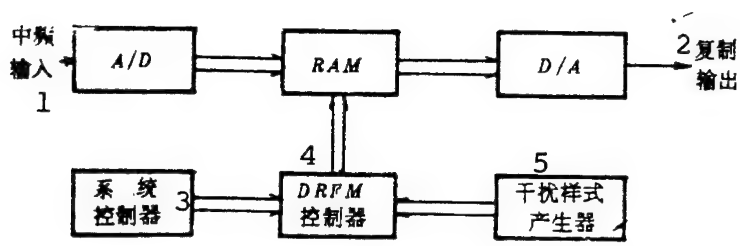

Fig. 3. Block diagram showing DRFM principle of retransmission type fuse interferometer
KEY: 1 - intermediate frequency input
2 - duplication output 3 - controller of the system 4 - DRFM controller
5 - jamming pattern generator

The retransmission interferometer is a super-heterodyne retransmitter for time sharing, in which a solid-state delay line, a surface acoustic wave delay line, and a digital radio

frequency memory (DRFM), etc., are adopted for time delay. Fig. 3 is a block diagram showing the principle of super-heterodyne retransmitter based on digital radio frequency memory. When the super-heterodyne interferometer has searched and acquired a fuse signal, it converts the signal into an intermediate frequency through lower frequency conversion, and the intermediate frequency signal is then directly stored in the digital memory and again is converted into a radio frequency jamming signal through upper frequency conversion in the transmission system.

DRFM is a newly-born technology, which started to serve the armed forces in the mid eighties in some foreign countries. DRFM technology together with the controller of the jamming system as well as the jamming technology generator constitute the heart of the jamming system. In designing this kind of an interferometer, an important procedure is to correctly select the storage and access time and at the same time, to ensure the accuracy of jamming signal duplication as well as to prolong the transmission time of the jamming signal. By applying retransmission jamming, it is possible to improve jamming functions, raise the jamming frequency-aiming precision, and to continuously adjust the waveforms and parameters of the jamming signal with the variation of target parameters.

4. Conclusions

As an inherent low-information device, a fuse can receive only signals located at predetermined positions near the target. Thus, a fuse may be designed for narrow-band transmission and narrow-band reception; by controlling the starting time of fuse operation (i.e., delay power connection) so that the fuse can be ready to transmit only near the preset explosion position, it is possible to avoid a too early fuse explosion and reduce the time of electronic jamming; adopting special anti-jamming circuits, such as adopting nonlinear integration amplifier in continuous-

wave fuse, etc.

It becomes very difficult to jam a radio fuse once it is protected with multiple anti-jamming measures. At present, the sweep frequency jamming and retransmission jamming, which are being applied both at home and abroad, have proved to be efficient in dealing with the continuous-wave Doppler fuse. The jamming capabilities of the interferometer is closely associated with the unique features of the interferometer and the fuse as well as tactical conditions. In actual combat, however, it is difficult to determine the protection area of the interferometer due to many tactical factors.

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RESEARCH ON ANTIRADIATION MISSILE COUNTERMEASURES USING TWO-POINT SOURCE TECHNOLOGY*

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ABSTRACT: Analysis shows that with two point sources, it is extremely difficult for antiradiation missiles to hit either of them. It is believed, therefore, that two point sources have the capability of counterattacking antiradiation missiles as long as they operate simultaneously and are arranged at an appropriate distance from one another.

KEY WORDS: two point sources, antiradiation missile countermeasures.

1. Analysis of Principle

Two point sources A and B are assumed to be positioned at distance d from each other, and both A and B are within the acquisition range of an antiradiation missile, as shown in Fig. 1. This assumption is made because antiradiation weapons feature broadband and wide beams. As the two point sources

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the receiver of an antiradiation weapon at the same time, the transmit signals into respective signal intensities that the tracking antenna of the antiradiation weapon receives are shown in Fig. 2.

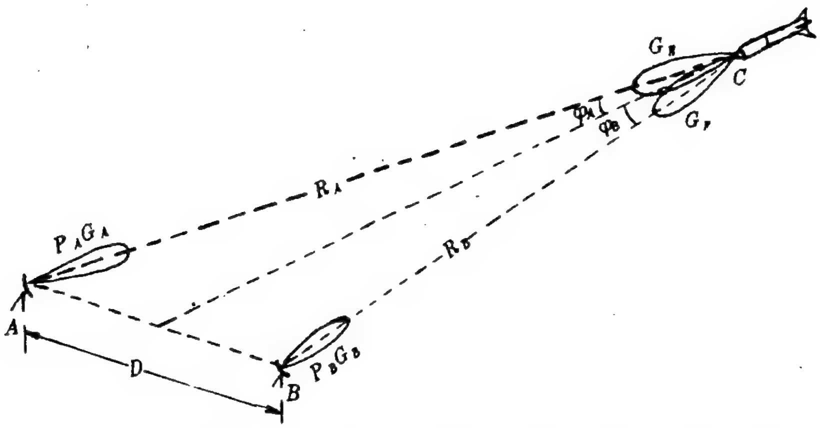

Fig. 1. Location of two point sources against an antiradiation Missile

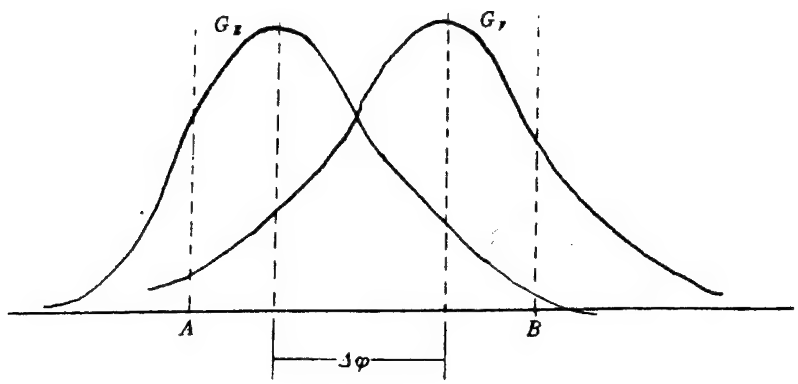

Fig. 2. Signals of two point sources received by an antiradiation weapon

The signal intensity from point source A that an antiradiation missile receives is:

$$\left.\begin{aligned} P_{EA} &= \frac{P_A G_A}{4\pi R_A^2}\,\frac{\lambda^2}{4\pi} G_E(\varphi_A) \\ P_{FA} &= \frac{P_A G_A}{4\pi R_A^2}\,\frac{\lambda^2}{4\pi} G_F(\varphi_A) \end{aligned}\right\} \qquad (1)$$

The signal intensity from point source B, received by an antiradiation missile, is:

$$
\left.\begin{aligned}
P_{EB} &= \frac{P_B G_B}{4\pi R_B^2} \frac{\lambda^2}{4\pi} G_E(\varphi_B) \\
P_{FB} &= \frac{P_B G_B}{4\pi R_B^2} \frac{\lambda^2}{4\pi} G_F(\varphi_B)
\end{aligned}\right\} \tag{2}
$$

The error voltages of the two point sources A and B, ΔU_A and ΔU_B, respectively, are:

$$\Delta U_A = \frac{1}{2}[\log G_E(\varphi_A) - \log G_F(\varphi_A)] \cdot K \tag{3}$$

$$\Delta U_B = \frac{1}{2}[\log G_E(\varphi_B) - \log G_F(\varphi_B)] \cdot K \tag{4}$$

where K is the amplification coefficient of error voltage. If point sources A and B operate simultaneously, the angular tracking error voltage that the antiradiation weapon acquires is

$$\Delta U = \Delta U_A + \Delta U_B \tag{5}$$

By substituting Eqs. (3) and (4) in (5), we obtain

$$\Delta U = \frac{K}{2} \log \frac{G_E(\varphi_A) \cdot G_E(\varphi_B)}{G_F(\varphi_A) \cdot G_F(\varphi_B)} \tag{6}$$

For visual understanding, Eq. (6) can be plotted as curves, which are shown in Fig. 3.

ΔU_A, ΔU_B, and ΔU in the above figure conform to the foregoing implication. It can be seen from the figure that with two point sources, the aiming point of the antiradiation weapon is neither A nor B, but M that is located between A and B. This indicates that if two point sources operate simultaneously, the antiradiation weapon can aim at neither of them, and its intention of hitting both will never succeed. When the signal from point source A is intense (with a higher effective radiation

power), the point M (aiming point) moves to A; when the signal from point source B is intense, it moves to B. While the signal intensities from A and B are equal, M is right in the middle of them. This confirms that the two point source technology can be used to counterattack antiradiation weapons as long as the two point sources can provide a proper radiation intensity and are positioned at a proper distance between them.

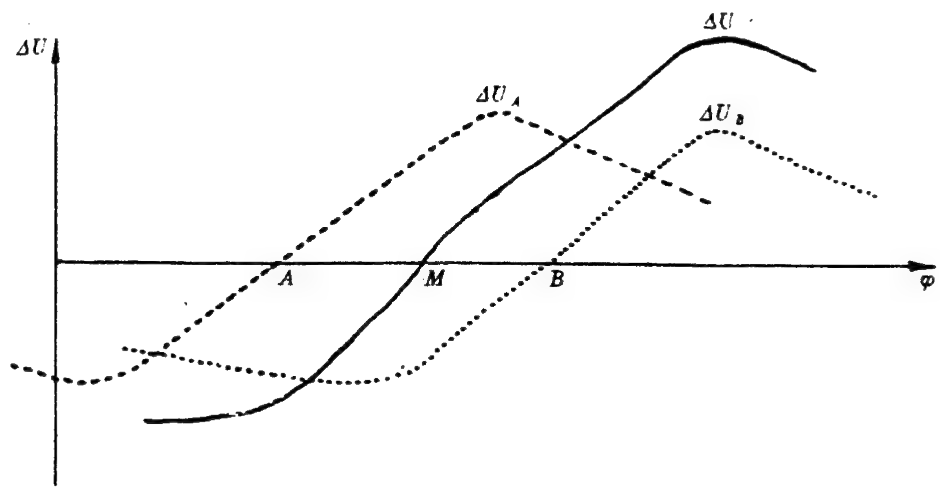

Fig. 3. Error voltage curves of an antiradiation weapon under two point sources

2. Application Examples

The foregoing analysis suggests that the two point source technology is efficient in counterattacking antiradiation weapons. Therefore, this technology together with its concept can be used to protect ground air defense networks and ground jamming stations from being attacked by antiradiation missiles. As shown in Fig. 4, A is assumed to be a high power jammer; B is an active bait which is at distance D from A; C is the attacking antiradiation missile and G is a warning aircraft.

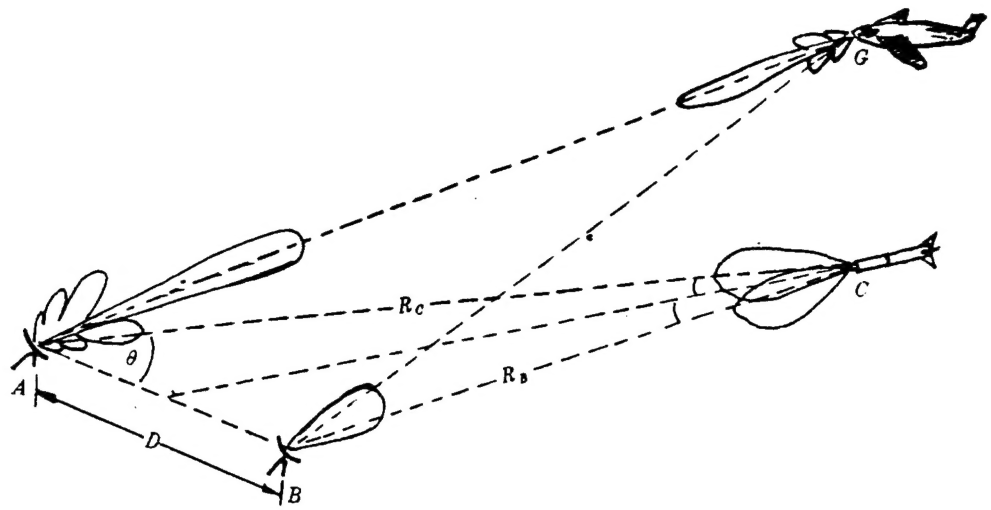

Fig. 4. Location of high-power jammer and bait against antiradiation missile

It is also assumed that the antiradiation missile is in low-altitude entry while approaching the attacked target and therefore, the elevation angle can be ignored in calculations.

According to Eq. (1), the signal power P_1 that the antiradiation missile receives from the parasitic lobe of the main jamming station, and the signal power P_2 that it receives from the auxiliary bait station, respectively, are:

$$P_1 = \frac{P_A G_A(\varphi)}{4\pi R_C^2} \frac{\lambda^2}{4\pi} G_C(\theta_A) \qquad P_2 = \frac{P_B G_B}{4\pi R_B^2} \frac{\lambda^2}{4\pi} G_C(\theta_B)$$

where $G_A(\varphi)$ is the gain of the parasitic lobe of the main jammer (the parasitic lobe subtends the angle φ with the main lobe). Suppose:

$$Y = \frac{P_2}{P_1} = \frac{P_B G_B G_C(\theta_B) R_C^2}{P_A G_A(\varphi) G_C(\theta_A) R_B^2} \tag{7}$$

and let

$$\frac{P_B G_B G_C(\theta_B)}{P_A G_A(\varphi) G_C(\theta_A)} = N(\varphi, \theta) \tag{8}$$

then according to the geometry in Fig. 4, the following can be derived: $R_B^2 = R_C^2 + D^2 - 2DR_C \cos\theta$

From Eq. (8),

$$Y = \frac{R_C^2 N(\varphi.\theta)}{R_B^2} = \frac{R_C^2 N(\varphi.\theta)}{R_C^2 + D^2 - 2DR_C \cos\theta} \tag{9}$$

The mean square root value of N(φ, Θ) is evaluated as 0.8, based on which the Y value can be calculated at different distances (R_C value) while the antiradiation missile enters at different angles (Θ value). Fig. 5 shows curves plotted in accordance with the foregoing calculations while D=3km; Fig. 6 shows the curves calculated when D=1km.

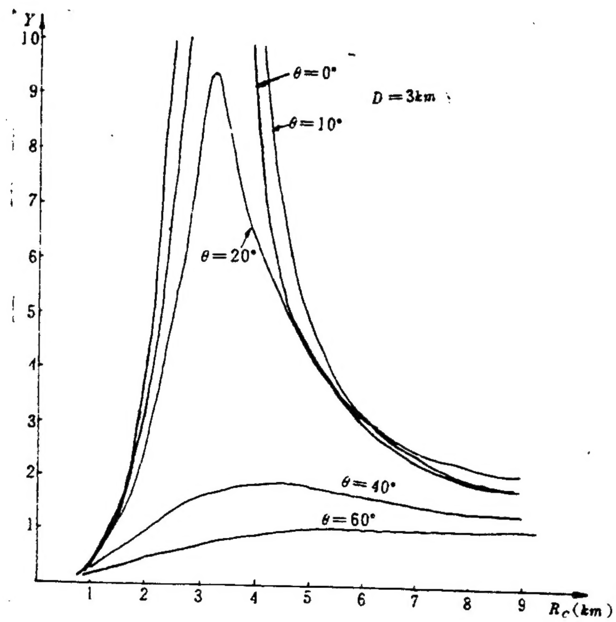

Fig. 5. Relationship between Y value and distance while D=3km

It can be seen from Eqs. (3) and (5) that with the operation of two point sources, it is extremely difficult for an antiradiation missile to hit the target as long as the two sources are aligned at a proper distance.

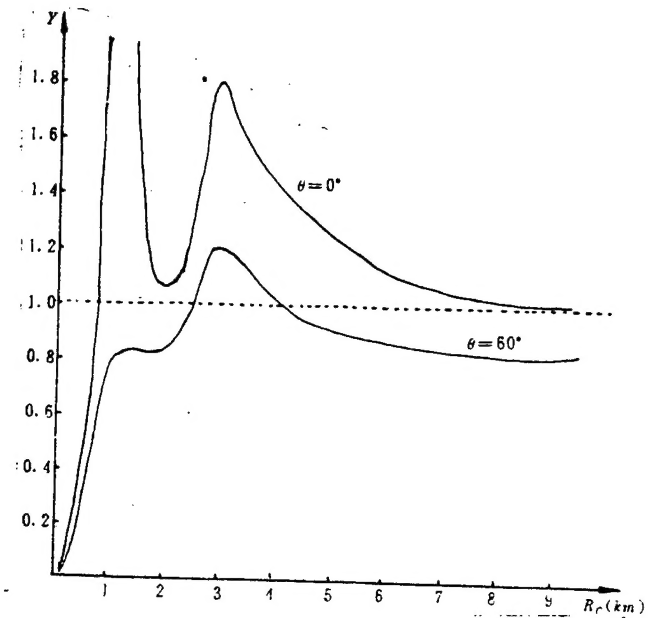

Fig. 6. Relationship between Y value and distance while D=1km

While Fig. 6 indicates that if the distance between the main jammer and the auxiliary station (bait) is set at 1km, the power ratio between signals received by the antiradiation missile from the main and auxiliary stations varies in the neighborhood of 1 within the range 2-9km while $N(\phi, \Theta)=0.8$ is in the neighborhood of 1. In other words, the antiradiation missile points at the middle between the main and auxiliary stations instead of either one of them. In Figs. 5 and 6, $Y>1$ implies that the aiming point of the antiradiation missile inclines to the bait, which obviously is advantageous for protecting the main station.

3. Conclusions

In recent years, antiradiation missiles were successfully applied in many regional wars in the sense that they could offer a high probability of hitting single point sources as an efficient deterrent means. However, in the case when two radiation sources operated simultaneously hundreds of meters apart, the antiradiation missiles never hit any target in

warfare. Again, our analysis further confirmed that two uncorrelated point sources truly can possess the capabilities of counterattacking antiradiation missiles while operating simultaneously at a proper distance from each other.

This paper was received for editing on January 5, 1996, and the edited paper was received on January 9, the same year.